Water Supply Engineering
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Lecture-35
Disinfection Basic

Hi friends so we are halfway through this course water supply engineering and in previous six weeks we have discussed the different aspects related to the basics of water availability then how do we estimate the demand how do we withdraw the water. Then we did talk about these storage structures as well and since last couple of weeks we are focusing on the quality aspect of water and we did talk about the basic water treatment processes.

Starting from the like very basic aeration and then which is in fact optional and mores over the like sedimentation coagulation flocculation and filtration processes. So, this week will be talking about the another treatment step which is in fact the most important you know water supply system which is disinfection and apart from that will touch upon the few other options of advanced water treatment systems. So that is what basically we will be covering in this particular week.

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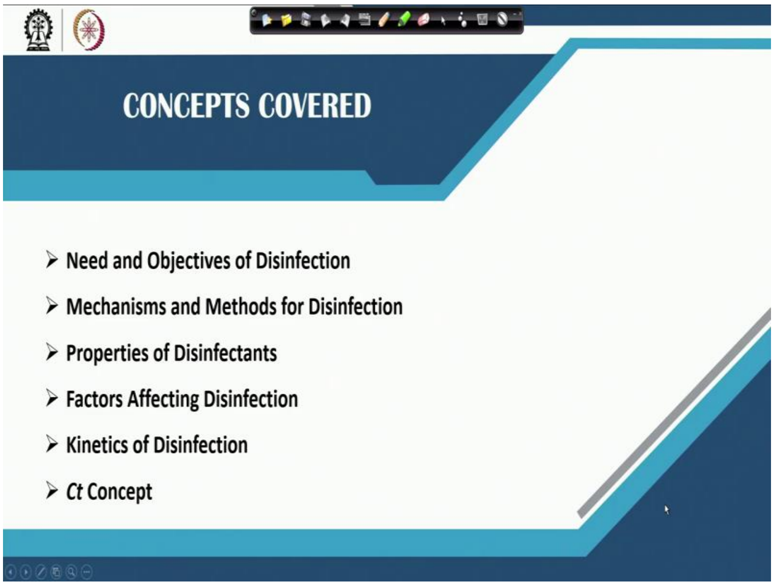

In this class we will be talking about the disinfection process the basics of disinfection so what is the need and objective of the disinfection the mechanics and the different methods for the disinfection. Then we will talk about the what should be the ideal properties of a disinfectant and what are the common properties of the disinfectant that are there and that people generally use. We will be talking about the factors affecting disinfection and the kinetics of disinfection including the CT concept.

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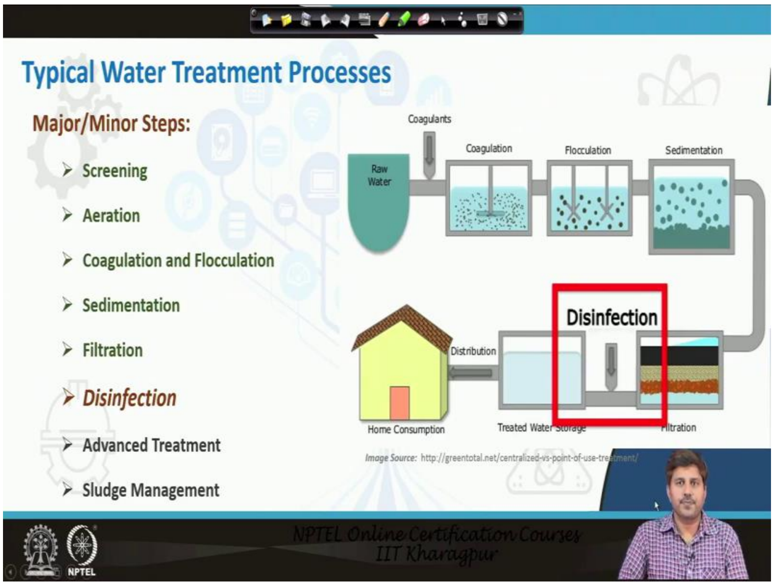

So, as just we are having a brief discussion earlier if you see a conventional water treatment system and particularly brought form a surface water sources. So, what we get is the coagulation filled flocculation sedimentation filtration process all this we have already covered. And this week we will be focusing on this disinfection process so all this we have almost covered. And then advanced treatment and sludge management also we will try to cover in this week itself.

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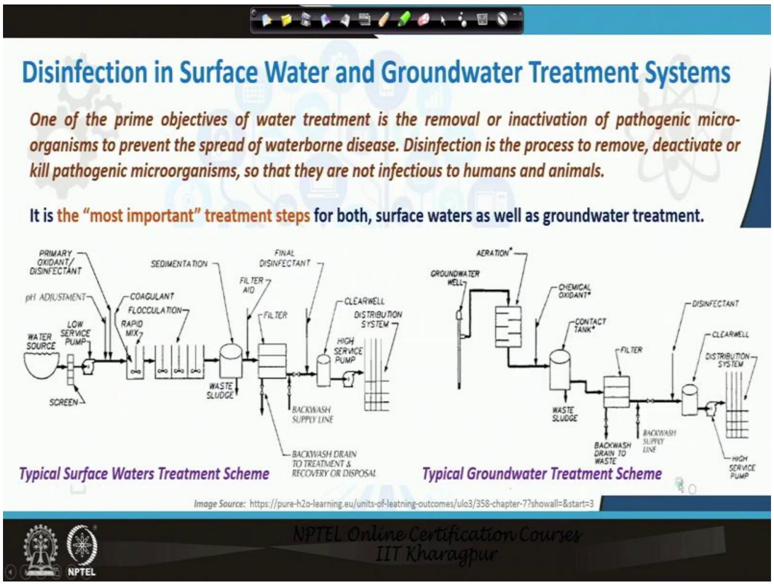

The disinfection is one of the most important treatment steps for both surface water as well as ground waters and that is because the aim of disinfection is the removal or inactivation of pathogenic microorganisms. And this is the most one of the most prime objectives of the water treatment systems. Generally the water treatment focuses like the quality of water which is supplied should be safe.

Now in order to be safe the impurities has to be removed now what are the impurities that are typically removed we talked about the impurities like the so far what we have discussed if you just remember that so we discuss mostly the removal of these suspended impurities suspended solids, suspended and colloidal solids in fact through coagulation flocculation process. So, we rarely target the removal of dissolved constituents that too in conventional water treatment systems unless there is a known case of a problematic substance which is dissolved in the water.

If we are knowing that this particular water source has say a high concentration of arsenic high concentration of fluoride high concentration of say some other heavy metals or some toxic compounds. Then the specific treatment might be provided for removal of those compounds otherwise the typical surface water systems if you see just take the water then put through a coagulation flocculation system and then sedimentation then filtration and after that if you see the disinfection process and then clear water is basically water is put for the uses.

So, similarly if you see the groundwater system if our idea is not the removal of some other things, so normally we may provide aeration again this is an optional if you are targeting iron and those kind of removals we may provide, otherwise it may just go to the filtration in fact for groundwater system many times even filtration is also I did or this slow sand filter might be provided in a small if the requirement are smaller. And then disinfection and then it is goes to the clear well for supply purpose.

So, that is what is the like importance of disinfection before supply the disinfection unit is provided in all in like both these systems, so here we have disinfection and then clear well which goes for supply similarly here we have disinfection and then clear well which goes for the supply purpose now. Why it is put in the end and why we consider this as the most important treatment step because the coagulant addition which takes care of say or the colloidal solids or the sedimentation process which take care of the; like removal of these flocs form through coagulation flocculation.

Or the existing suspended materials in the water or filtration which typically take care of the majority of the micro flocks and the very fine sediments so by the time water comes out of the filtration it is divided off particularly these solids mostly if we are going for multi media filter some organic compound might also be removed through adsorption some dissolved compound might be removed through adsorption process.

But again that is it whereas the major threat of a contaminated water supply is if the water is having say microbial contaminants. Why microbial contaminants? Because these are the substances which leads to the acute problems what happens that when there are microbial impurities present in the water and somebody's coming into the contact of that water or drinking that water or consuming that water.

In any way that microbes that pathogen is entering into the body of the consumer be it human or be it animal it is entering into the body of consumer and as you know that when these interns it is not like if a little of heavy metal goes inside the body it is not going to create any immediate problem. So, even arsenic fluoride which is considered to be like very, very problematic geoginic contaminant does not so immediate impact they needs time to accumulate.

But these pathogenic impurities pathogenic contaminants as soon as they come into our food chain or into our body within a few hours or just a couple of days the person will start feeling those symptoms and they know that they have consumed some impure water contaminated water. So, that is why the water treatment ensures that these kind of pathogens pathogenic microorganisms are either removed or inactivated in the water and this process is known as the disinfection.

So, disinfection is mixed basically the process for removal for removing the deactivating or killing the pathogenic microorganisms. So, that they are not in phases to the consumers and consumers which could be human being or which could be animals.

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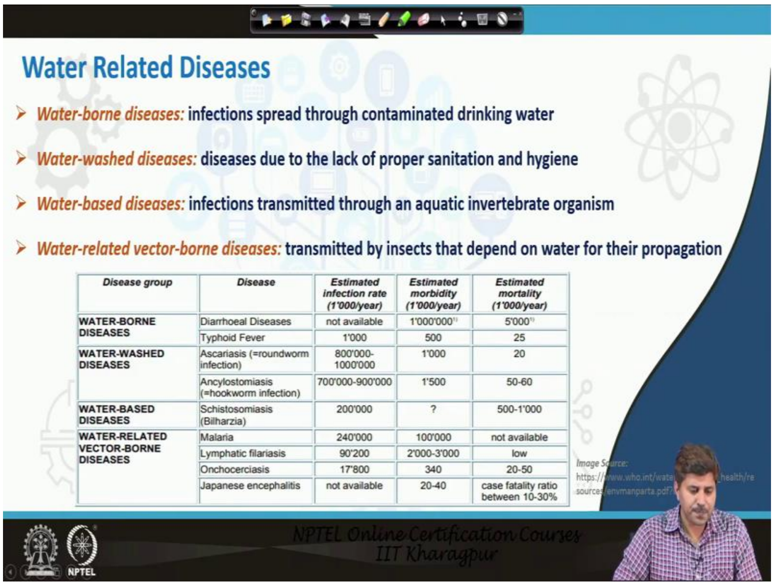

Typically water related diseases if we see we can classify them into 4 different types one is the waterborne diseases which are the infection spread through the contaminated drinking water like the diarrhea or typhoid. Then water wash diseases these are diseases due to the lack of proper sanitation and hygiene so when there is a lack of water so we may have like round worm infections or hookworm infections kind of diseases the water was diseases which is not of too much concern for us.

The primary concern for us is actually the waterborne diseases there are water-based diseases where are the infections transmitted through an aquatic invertebrate organism. So, they are not necessarily because of contaminated water but they get transmitted because of some organism which is dependent on the water and then again water related vector borne diseases are transmitted by the insects that depend on water for their propagation.

So the like by doing disinfection we target the removal of these part the waterborne diseases we want to make the water safe, so that these waterborne diseases which is because of the in fact sense for the contaminated drinking water means the water which is having the these kind of pathogens.

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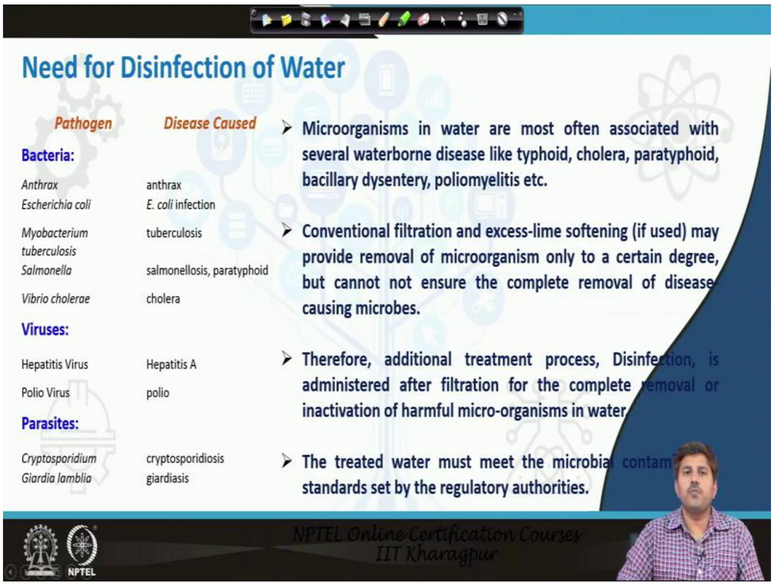

So, we want to prevent the infections causing because of consumption of such water and that is the prime need or prime objective of the disinfection. So, if you see the basic requirement for disinfection this microorganism in water are most often associated with various diseases like typhoid, cholera then dysentery, polymerized. So, there are various diseases the conventional filtration or even in case of like people are using access line softening also.

So they do provide some removal of microorganisms some removal of these pathogenic microorganisms but only to a certain degree they cannot ensure the complete removal of these disease-causing microbes. So, if they are not able to completely remove this that means we need to have an additional process or some additional measure to remove that and that additional process is actually the disinfection.

So, disinfection is basically administered after typically the filtration for the complete removal or inactivation of these harmful microorganisms that are present in the water. And the goal is that we meet whatever the regulatory standards are there for the pathogenic contaminations like EPA has 1 peony up in say 100 ml of water or that kind of that like for MPN should be zero close to zero in as per Indian Standards.

So those limits are there these are typical like this why we want to basically go for disinfection because there are various pathogens which may relate various kinds of diseases. So, in order to like ensure your safety from these diseases so that these diseases are not caused in order to ensure the safety we want to remove these from the water. So, if we remove these from the water will be actually safe from these diseases which might actually affect the end consumers.

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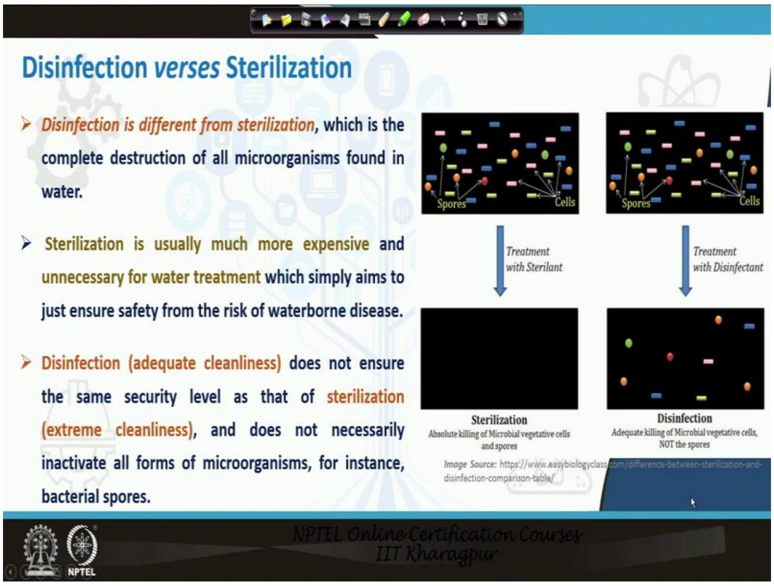

Now there is another term in fact the sterilization which often people get confused with. So, disinfection is not essentially sterilization there is a difference between disinfection and sterilization and the difference lies in to what extent we want to see the removal or hand up means what approach we are adopting for handling of the microorganisms. So, disinfection is characteristically different from the sterilization.

Sterilization is the process which ensures complete destruction of all the microorganism found in the water. Whereas disinfection ensures it is basically the adequate cleanliness only it does not ensure the same level of security as that of sterilization which ensures the extreme cleanliness so disinfection will not necessarily like inactivate or kill all forms of the microorganisms like the bacteria dispersed spores might still be there.

Sterilization removes everything but it is much more expensive and unnecessary for water treatment we do not want that level of security in water treatment. We want just like to be sure that pathogens are not there or any disease-causing organisms are not present in the water. So, the disinfection simply aims to just ensure safety from risk of the waterborne diseases whereas the sterilization is the complete removal.

So like if say we have cells and spores present in a water sample and we want to treat it with a sterile end then it will actually be all spores all cells everything will be removed or sort of killed in the water there is no life cells or life spores present here. But in this infraction we will remove the pathogenic sports and cell and we can still have some sports and some cells present in the water. So, particularly like it most of the like vegetative cells it will kill not all the spores so that is the difference between the disinfection and sterilization process.

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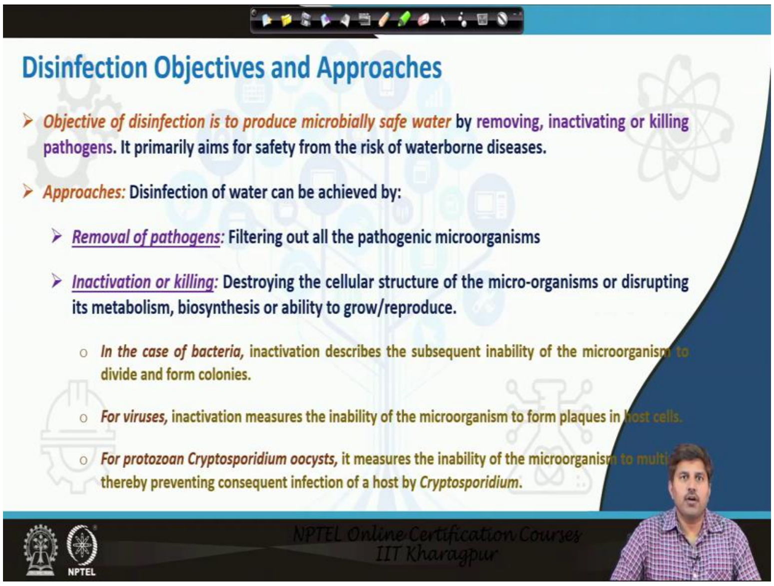

Now the objective of disinfection is clear that we want to produce a microbe release safe water by removing in activating or killing all the pathogens present in the water remember pathogens right. So, it primarily aims safety from the risk of waterborne diseases that is what is the major objective of the disinfection process. There are there are major way like two approaches of achieving disinfection as we are just discussing.

We can remove them so the removal of pathogens we can filter out all the pathogenic microorganisms. So, we can use like high-end filters nano or higher grade filtration processes or we inactivate or kill all the microorganisms. So, inactivation or killing is basically the destroying the cellular structure of the microorganisms or we disrupt its metabolism biosynthesis or the ability are to grow for these microorganisms ability to grow and reproduce for these microorganisms.

So in case of bacteria the inactivation is basically by the subsequent inability of microorganisms to divide and form colonies in case of viruses. This inactivation means the inability of microorganisms to form the place in the host cells and for protozoa or Cryptosporidium kind of species it basically measures the inability of these microorganisms to multiply thereby preventing the consequent infection by this host protozoa. So that is what is the approach for inactivation and the other approach is simple filtration.

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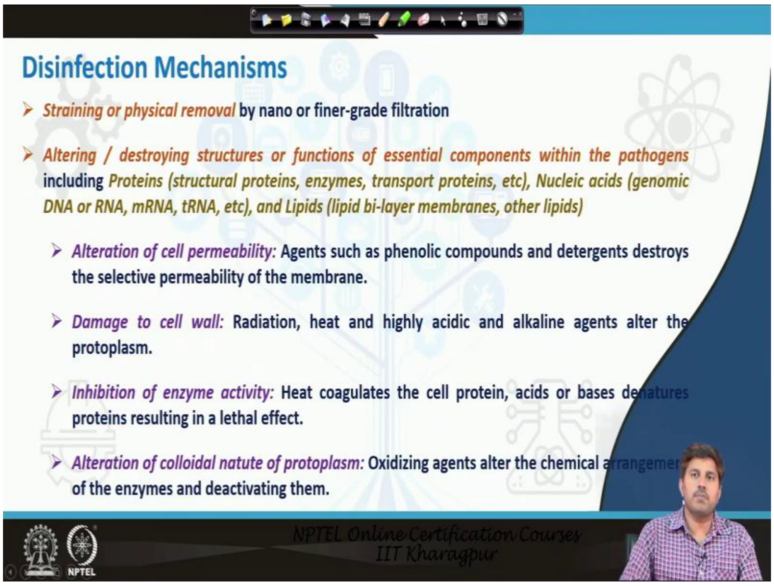

Then if we talk about the mechanisms of disinfection again if we are taking the filtration approach so mechanism is simply like straining or physical removal by nano or nano grade or finer grade filtration processes. Whereas if we are going for altering or destroying the structure or function of the essential components so we can actually use like we can disrupt the protein structures or functions including structural protein, proteins enzymes or the transport proteins we can target nucleic acid or we can target lipids.

This can be done by the alteration of cell permeability so like the phenolic compounds and detergent types work on this. So, they affect the selective permeability of the membrane. This can be done by damage to the cell walls so chlorine and those kind of things are even radiation and heat or highly acidic and inclined agents can alter the protoplasm of the cell walls. This can be done by inhibition of the enzyme activities so cell proteins acids basically can be correlated by the acids and bases.

And the alterations of the colloidal nature of protoplasm so basically the oxidizing agent alter the chemical arrangements of the enzyme and kind of deactivate them. So, this is one of the major mechanism many of the meaning of the disinfectant target like oxidize target to oxidize the chemical arrangement of enzymes and basically deactivate them.

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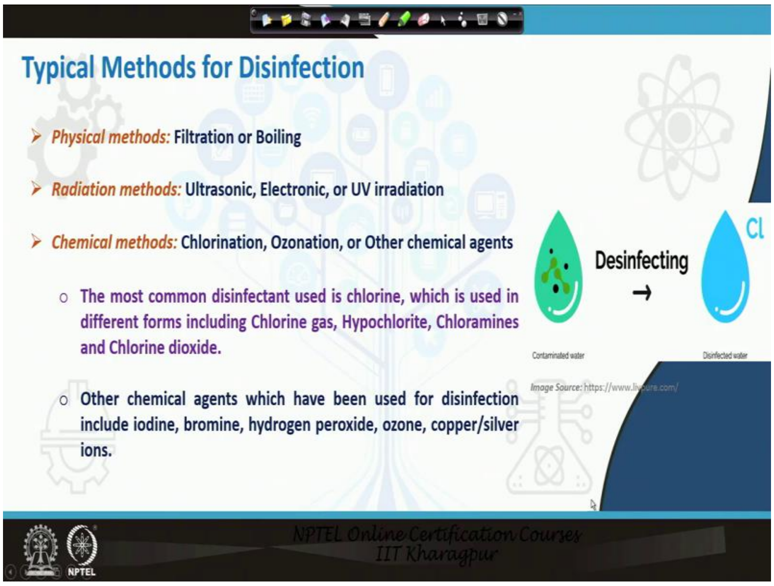

So, typical methods for disinfection include the physical method which is filtration or boiling then there are radiation methods a physical method means we can simply filter out or boil there are radiation methods we put an ultrasonic electronic or the UV radiation exposure to the microorganisms or there are chemical methods where we use like chlorination or ozonation or other chemical agent.

So, the most common disinfectant worldwide is actually chlorine that is what is the most common one and this is used in the different forms it can be used in the chlorine gas it can be used as the hypochlorite is can be used as chloramines or chlorine dioxide. The other agent which have been used for disinfection the chemical agents particularly are like iodine then bromine hydrogen peroxide ozone copper silver ions some acid base acids and bases are also used but they are more used in the wastewater systems.

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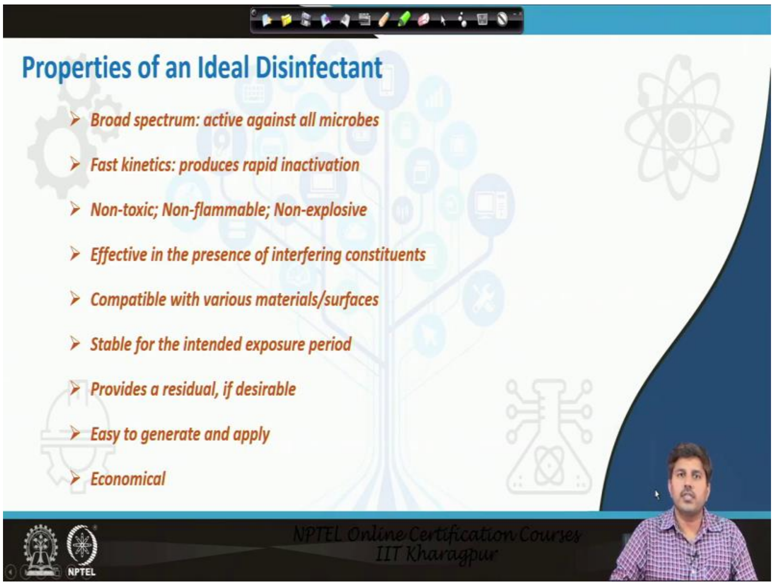

Water supply systems generally like either chlorination is by far the most popular and then people do use the ozonation or UV exposure as the common method. Heating is again traditional method for chlorination very small scale it is used and household level people might use heating as a chlorination method but again because of lot of energy requirement it is not a preferred approach for chlorination.

So an ideal disinfectant if we see should have the broad spectrum that means it should be active against all microbes it is not like you use a disinfectant which is effective against bacteria but not effective against virus or protozoa Cryptosporidium Giardia kind of species is then probably it is not serving the purpose. So, whatever is disinfectant or whatever disinfection method is being choosed must have a broad spectrum so that it is active against all sorts of pathogenic microbes.

It should have fast kinetics means the inactivation should be rapid if it is very slow it requires a lot of exposure time for deactivating or for kind of in activating the microorganisms in that case the size of the disinfectant unit is going to be large and cost is going to be high. It should be non-toxic non-flammable non-explosive again like for the safety purpose it should be effective in the presence of interfering constituents.

This is very important there might be various interfering constituents present in the water depending on the raw water quality that we are receiving and the disinfectant that we are using should actually be effective even if these interfering agents are present. Otherwise we add disinfectant and because of some interfering agents it is not causing that the like it is not fulfilling its intended objective it is not leading the inactivation of the microorganisms or pathogens that means our disinfection has not been achieved even after adding the disinfectant.

So it should be actually like other way it the disinfectant that we are adding should be effective even if some interfering constituents are present in the water. It should be compatible with various material surfaces so like because we may use different kind of pipes for supply for water supply different materials for making tanks and those things. so, whatever disinfectant we are using should be compatible with all these materials.

It should be stable for intended exposure period so if you want to say have exposure period of 20 minutes or disinfectant this in fact in whatever we are adding should be in the stable form till 20 minutes. So, that it can actually cause the intended effect it is not that the compound itself is changing form. So, then we will not be able to achieve the desired in fact disinfection. Again it should provide a residual if desirable.

So this is very valid for particularly chlorination for chlorine we will discuss the residual chlorine concept in the later class. But the point is that the disinfection should provide a future safety if possible. Otherwise by the time the chemical is in contact with the water it is say taking care of any sort of pathogenic pollution but when water again goes off so that time particularly it should be water.

If there are residual disinfectant present then they will ensure that even if later some pathogens comes into the contact of water that will also be disinfected. If there is no residual chlorine in the if there is no residual disinfectant in the water or no residual effect like you boil the water you have cooled it now if again some contamination come that will persist in the water that is not going to get died.

But say for chlorine if you have added chlorine in the water and have left little chlorine in the water itself so then when you when some other contaminant come into the contact of that water the residual chlorine present in the water will disinfect even the like those pathogenic elements which are coming later on in the contact of the water. Again it should be easy to generate and apply and should be economical. So, that is the major like requirements for an ideal disinfectant.

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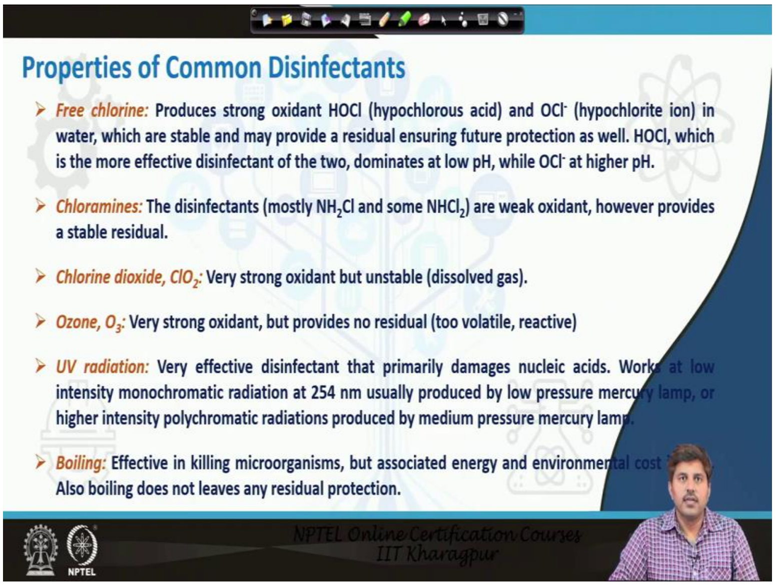

If we see the properties of common disinfectant that we have so that was about like how an ideal disinfectant should be. But like the common disinfectant that we use is free chlorine is one of the disinfectant. So, this produces strong oxidant HOCl and ocl which are hypochlorous acid and hypo chloride ions in water and these are quite stable and provide a residual effect also for future protection as just we were discussing.

HOCl is more effective disinfectant of the two means HOCl is more effective than OCL ions hypochlorite ions and HOCl dominates on low pH whereas if pH is high we will see that hypochlorite ion's dominate over hypochlorous acid. Then there are chloramines which are mostly NH like mostly the mono chloramine sometime when dye chloramines also both of them have some disinfection abilities mono chloramines have higher than di chloramines.

But relatively like if you compare it with the hypochlorous acid on hypochlorite ions these chloramines are weak oxidant and although they are also stable and provide a residual effect. They are in fact more stable than the hypochlorous acid and hypo chloride ions but their potential of oxidation is weaker as opposed to the free chlorine residuals. Then the chlorine dioxide is a very strong oxidant but again very unstable and costly also requires skilled expertise it needs to be generally produced at the site itself.

Because of its unstable nature so that is why it is although it is a very strong oxidant but not very, very rarely used not much used then ozone again a very strong oxidant but provides no residual effect it is too volatile and reactive that way the UV radiation is again a very effective disinfectant that primarily damage the nucleic acids. The nucleic acids are damaged when UV when basically UV exposure is received by the microorganisms. It works at low intensity like low intensity monochromatic radiation at 254 nanometer.

Or it can work at a higher intensity polychromatic radiations which can be produced from the medium pressure UV lamps whereas the low intensity monochromatic can be produced from the low pressure mercury lamps. Boiling is another method which is effective in killing microorganisms but again the energy and environmental cost is very high. So, as a result it is not considered also it does not provide any future protection there is no residual safety in the boiling.

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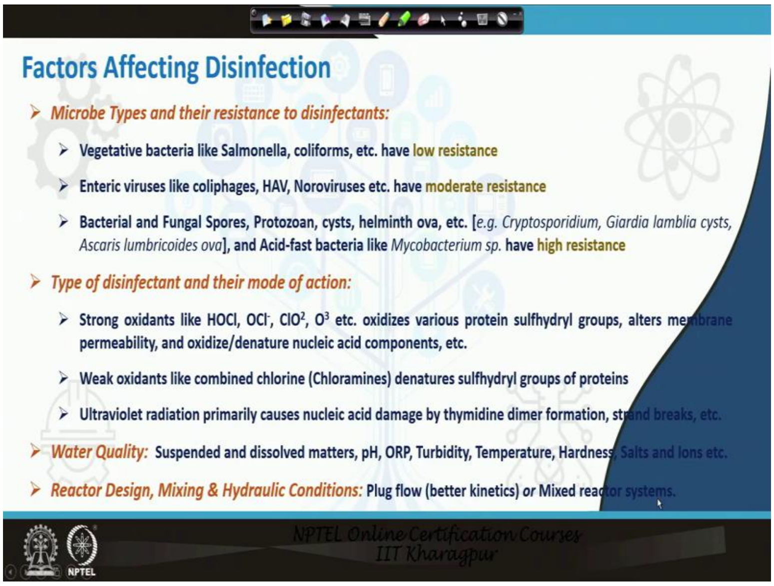

Then the factors that affect the disinfection process there are like the first important thing is here what types of microbes are there what types of microbes are being targeted and what are the resistance of these microbes to the disinfectant that is being used. So, microbes itself may have like different grade of resistance some microbes have very high resistance and they are very difficult to remove through the disinfection process or normal disinfection process.

Some microbes have very low resistance and even a small exposure of say chlorine or UV or any oxidant can easily take care of those microorganisms. So, like if you see the vegetative bacteria like Salmonella species or kohli forms they have very low resistance easily removable then enteric viruses like HIV or norovirus etcetera they have moderate resistance whereas various bacterial and fungal spores protozoa cysts helminth is like Cryptosporidium Giardia these things and micro bacterium kind of a species has very high resistance.

So, these are difficult to remove now if we are targeting the exposure of say our disinfectant such a way that it is take it basically take care of the removal of these species then these will automatically get removed but because of they have much lesser resistance than this but if our like the ability of disinfectant or the exposure time or the level of disinfectant is not sufficient enough so then we may see that these and maybe these get removes.

But some of these species which have very high resistance they might still persist in the water. It also depends on the type of disinfectant and their mode of action so as we just discussed there are HOCl, OCL chlorine dioxide ozone are the strong oxidants they like they can affect the protein groups they can alter the membrane permeability they can oxidize denature the nucleic acid compounds there are weak oxidants like compound like combined chlorine chloramines etc.

So, they denature the sulphide really groups of the proteins whereas UV radiation primarily cause nucleic acid damage as just we were discussing and this might be like thymidine dimers function or it can basically break the strands of the nucleic acid. Water quality is also affects the disinfection process the suspended and dissolved material matters present in the water they might actually prevent say if you are using a UV and there is a lot of turbidity.

So, these turbidity sell this turbidity or the suspended or particles or the correlated materials might actually prevent the UV light to interact with the with the microorganisms so that way it can actually prevent or reduce the efficiency of the disinfectant, pH also plays a very important role many of these disinfectant have so different properties at pH like we were just discussing that HOCl or hypochlorite hypochlorous acid which is a stronger disinfectant than hypo chloride ions persist at lower pH whereas the hypo chloride ions persist at higher pH.

So pH also plays a role ORP what is the reduction potential of the medium itself if you are adding oxidant and water itself is having say lesser ORP or there are lot of reducing agent present so instead of like quickly going for the disinfection these if particularly for the chemicals they will get consumed in the like with the reducing compounds then turbidity temperature hardness salt and iron concentration all will have some sort of effect on the disinfection process.

It also affected based on the reactor design mixing and hydraulic conditions. So, plug flow systems as we discussed earlier also where basically water flows in the form of plug and it ensures that adequate time is given in the system. So, plug flow kind of system or pipe flow kind of systems are preferred for disinfection purpose as opposed to the mixed reactor or batch reactor systems.

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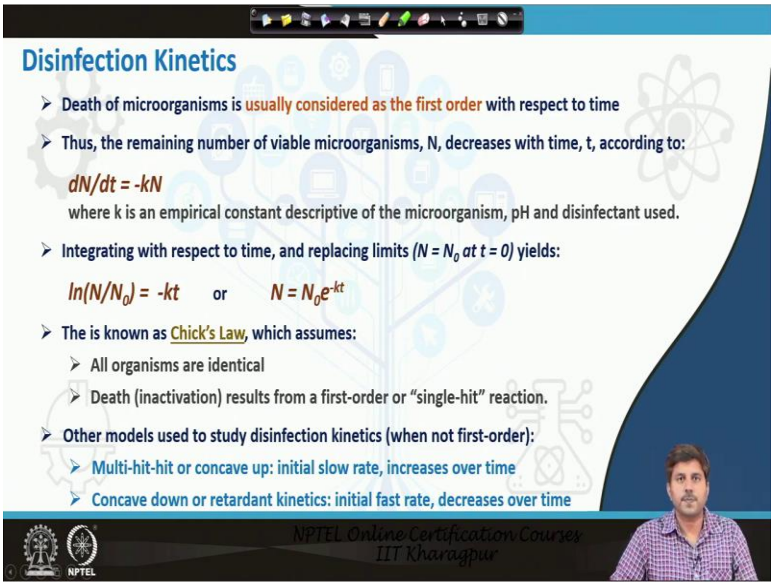

Now the disinfection leads to the death or inactivation of micro organisms with respect to time and that is usually considered as first-order if we see the kinetics of the disinfection. So, first order simply like if N is the number of microorganisms it will decrease with respect to time as dN by dt like so first order means the rate of change of the number of micro needles is going to be proportional to the number of microorganisms and if we take a proportionality constant so it is going to be equal to K and it is negative change.

So, we have to put a negative so where K is basically an empirical constant. Now if we integrate with respect to time and replace the limit as n is equal to N0 initial number of the pathogens at time t is equal to 0 then we can get ln N by N 0 is equal to -kt or N is equal to N 0 to the power - kt it is a simple first order solution or exponential equation. So, this is typically known such Chick's law this equation Chick's law about the disinfection it is simple first-order equation whereas Chicks law assumes that all organisms are identical and the death or inactivation is resulted from the first order or single heat reaction.

So, that means as the disinfection is heating the microorganisms it is getting deactivated. So, a single heat reaction is leading to the deactivation and then we can see that the first-order kinetics can be adopted there are other models which are used to study the disinfection kinetics when it is not particularly the first-order. So, there is a model which is concave up model and which is actually the multi-heat model means it does not get in a single heat so that is basically like the first order model is typically like this exponential decay of the number.

This is initially there is rate is slow in multi heated model and later on it basically fasters. So, this is your multi heat model and this particularly like this kind of models are used when basically we see that the disinfection might not be achieved in the single heat so this is particularly concave up. So, initially there only process will be slow whereas later on it basically speeds up. And then there is a retardant kinetics which is concave down kind of system so in that one what we see that initially it is faster and then it slows down then basically some retardant retarded by bacteria get acquainted.

And then retardation properties appear and that is why the rate decreases over the time. So, that that is basically the concave down and this is concave up model so that way we can have the like other kinetic models for the disinfection.

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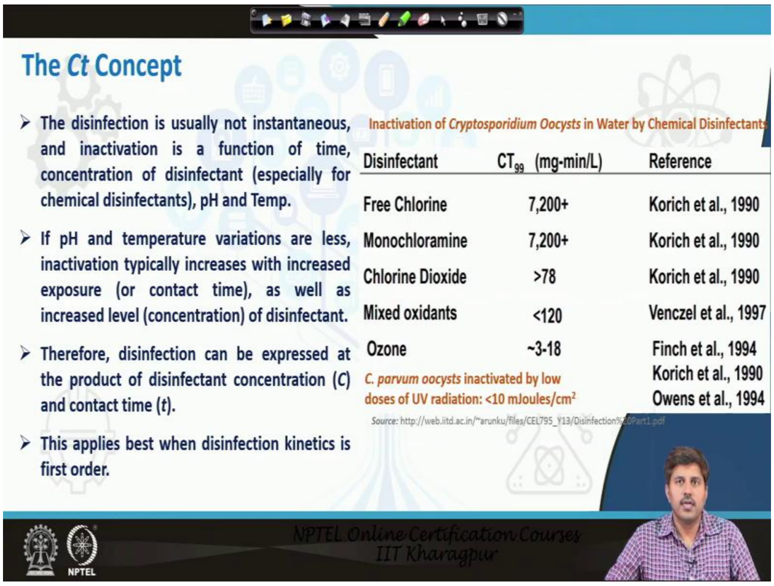

Disinfection is usually not instantaneous it needs some time as just we were discussing it is basically a kinetic process. So, it will require some time that is why it is considered as a function of time it is also considered as a function of the concentration of disinfectant is specifically if it is a chemical disinfectant. Because if say you are adding chlorine or ozone how much you are adding.

You cannot achieve same level of disinfection in a water if you add just 1 milligram per liter of chlorine and in another you are adding 10 milligram per liter of chlorine. Naturally the 10 milligram per liter of chlorine because the amount of oxidant is more is going to have higher effect or higher degree of disinfection as opposed to the 1 milligram per liter chlorine. So, it does depend on the concentration of the disinfectant it does depend on the time of the disinfectant like you have say 2 system.

In one system you are exposing disinfectant in the water for just a minute and in another you are exposing for 10 minutes. Now if those who are those organisms who are say resistant and may not get activated in just one minute so they will remain in the water if the exposure time is just one minute only whereas 10 minutes is giving far longer exposure time. So, those organisms are also likely to get disinfected or get in such medium.

It also depends on pH and temperature as we discussed earlier, so if pH and temperature variations are less we can consider the inactivation typically increases with increased exposure time or what we typically call the contact time in the case of chlorination and as well as it will increase with increased level of the concentration of disinfectant. So, disinfection means what kind of disinfection we are going to achieve can be expressed as a like product of this disinfectant concentration C and contact time t.

So that is why we call this C t and C t is an important parameter which kind of gives us an idea of the disinfection. So, this applies best when disinfection kinetics is the first order and more sever for the chemical because getting a concentration of like radiations or exposure frames for them is difficult. So, these are typically like inactivation of Cryptosporidium in water by the different chemical disinfectant Ct 99 means the 99% for Ct required for 99% removal or 99% inactivation.

So Ct unit will be of course like C's in a milligram per liter or something like that and t is the time so minute second or whatever so milligram minute per liter is the unit's here. When we are adding free chlorine the Ct value required is around more than 7,200 for 99% inactivation of the cost per dm for mono chloramines also it is greater than 7,200 for chlorine dioxide it should be more than 78. For mixed oxidant it should be like 120 is fine and ozone just 3 to 18 is the Ct value.

Now say the importance of Ct value like if we have an idea of these Ct values for say free chlorine it is 7200, so if we are exposing say if we are putting a contact time of say 20 minutes in the disinfection that means our Ct is 7200 and our contact time we have given 20 minutes, so the concentration that would be needed is 7200 divided by 20 so that means it is going to be 360 milligram per liter concentration we must ensure if we are going to do it for 20 minutes.

If you are going to do it for 40 minutes then this 360 will become just 180. If you are going to expose it for 10 minutes then instead of 360 will be requiring 720 milligram per liter concentrations. So, that is basically we need to ensure the Ct value so either we can increase the time and reduce the concentration or we can increase the concentration and reduce the time. Increasing concentration means more chemical requirement so we will have to see what is the cost associated with that and increasing time means the bigger contact tank.

Wherever we are putting the chlorine in the contact or say the disinfection in the contact so then we need a bigger tank because residence time is more. So, we will have to make a choice between this bigger tank means more installation cost and higher concentration means more operational cost so we will have to see what we want to choose how big tank we can afford and what chemical dosing we can offer in the system for the purpose of achieving disinfection.

So with this we will conclude this class here and in next class we will be talking about the different methods of disinfection primarily the chlorination which is by far the most used however we will touch upon some other typical method of disinfection like UV and ozonation which are used in the water supply systems, so, thank you and see you in the next class.